OBSERVATIONS ON NATURAL FELDSPARS: RANDOMLY DISORDERED STRUCTURES AND A PRELIMINARY SUGGESTION TO A PLAGIOCLASE THERMOMETER

By

Olav H. J. Christie

Mineralogisk Geologisk Museum, Oslo

a) *Randomly disordered feldspars*

A large number of K-feldspars from South Norwegian Precambrian rocks give X-ray powder patterns with diffuse $130/1\bar{3}0$ and $131/1\bar{3}1$ reflections whereas the other reflections are mostly sharp. (See also Goldsmith and Laves (1954)).

This may be explained by the existence of a multitude of very small volumes within the crystal, all having different degree of Si/Al order and contributing by their $130/1\bar{3}0$ and $131/1\bar{3}1$ reflections—the spacing of which differs from volume to volume—to form the bulk reflections. Based upon this model the notation Randomly Disordered was introduced (Christie (1962)). Another explanation to the blurred reflections may be found in the diffusing effect of anti-phase or out-of-step domain borders. The difference between the two explanations is mainly a matter of definition, and the final picture will be much the same when applying the more sophisticated conceptions of Laves and Goldsmith (1961) concerning the anti-phase boundary matter of anorthite.

It is difficult to give a quantitative description of the Random Disorder in K-feldspars. As a reference scale one may use the shape of the $131/1\bar{3}1$ peaks, as shown in Figure 1.

The diffraction range of the peaks from RD scale no. 4 to RD scale no. 7 correspond to a delta value of 1. Information on the $131/1\bar{3}1$ diffrac-

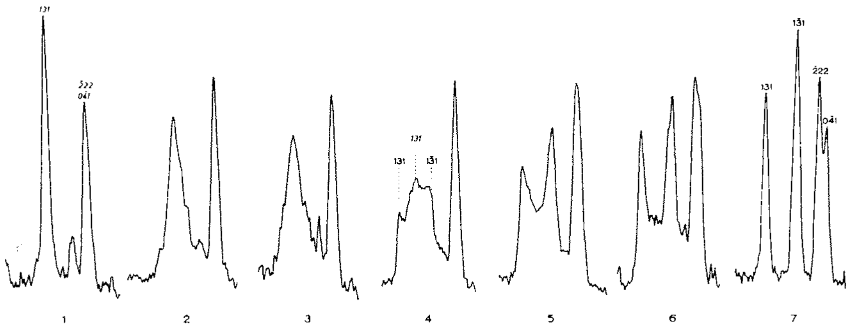

Figure 1. The *RD* scale, based upon the appearance of the $131/1\bar{3}1$ reflection pair of K-feldspar.

tion angle, which may correspond to delta values lower than 1, should always be recorded together with the RD scale number.

The RD scale does not give accurate information either on the structural or on the thermal history of the feldspar, it is a purely descriptive scale.

The geological conditions connected with the formation of Randomly Disordered K-feldspars are unknown. The extremely slow transformation from the initial and metatstable monoclinic state to the stable triclinic one, may at low temperatures favour the formation of Randomly Disordered K-feldspar, which in turn may exist for long geological periods. Thus, among the seven specimens used to illustrate the different Randomly Disordered K-feldspars, six were taken from Precambrian gneisses (Christie (1962)).

Both the temperature of formation and the water pressure influence the velocity of the Al/Si ordering process, and it is obvious that no definite information on the petrogenetic conditions can be obtained from X-ray powder data of K-feldspars alone. It may be significant, however, that Randomly Disordered K-feldspars occur frequently in augen gneisses as well as in pneumatolytic and hydrothermal environments, and that they are less abundant in pegmatites.

The optical data seem to confirm the X-ray data: the optical axes of Randomly Disordered K-feldspars are poorly defined, the cross-hatched twins are often indistinct and the extinction is more or less undulatory. However, the information derived from optical examinations is of even less quantitative character than the information obtained from X-ray powder analysis.

It is difficult to ascertain random disorder in plagioclases. The reflection pair $\bar{2}41$ and $24\bar{1}$ is a sensitive indicator, but the diffraction angles of these reflections are dependent both on thermal state and chemical composition of the plagioclase. Therefore, thoroughly zoned plagioclases produce X-ray patterns with blurred $\bar{2}41$ and $24\bar{1}$ reflections, thus being indistinguishable from the pattern of a Randomly Disordered plagioclase.

In a few samples, however, random disorder seem to have established. In several perthites from the Finnemarka Granite (NW of Oslo) both the K-feldspar and the plagioclase give X-ray patterns with strongly diffuse RD sensitive reflection pairs. Chemical inhomogeneity cannot explain the extreme degree of diffuseness and the structural state is possibly Randomly Disordered, maybe involving mutual structural influence of very small plagioclase and K-feldspar individuals.

Similarly, plagioclases from the contact between the Røsholmskjær pegmatite and the surrounding slightly granitised quartz-mica schist (near Kragerø, South Norway) give X-ray patterns with blurred $1\bar{3}1/131$ and $\bar{2}41/24\bar{1}$ reflections, and again a closer inspection of the specimens revealed that the differences in chemical composition within the sample could not fully explain the degree of diffuseness. These samples, therefore, seem to be Randomly Disordered.

It seems, thus, that the Randomly Disordered structure state exist in both plagioclases and in K-feldspars. Randomly Disordered plagioclases occur together with Randomly Disordered K-feldspars but have not been found together with non-Randomly Disordered K-feldspars. Random disorder is more common in K-feldspars than in plagioclases, and occur with or without Randomly Disordered plagioclases. This indicates that under similar conditions at lower temperatures the metastable Randomly Disordered state is more easily overpassed by plagioclase than by K-feldspar.

b) *A suggestion to a plagioclase thermometer*

It is possible to construct a plagioclase thermometer using the structural state and the An content as variables. The principle of this geothermometer is indicated in the papers by J.V. Smith (1956),

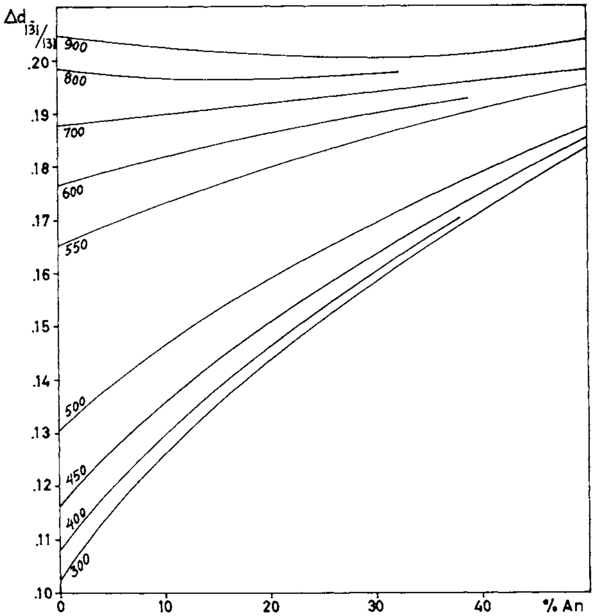

Figure 2. The plagioclase thermometer, data from Smith (1956), MacKenzie (1957) and McConnel and McKie (1960). Curve numbers 300–900 indicate geothermal degrees. $\Delta d\,1\bar{3}1/131$ is difference in d-values of the $1\bar{3}1$ and 131 reflections.

MacKenzie (1957) and McConnel and McKie (1960). The utility of the plagioclase thermometer is not known yet and this presentation should be considered as a preliminary paper to be supplemented by a more detailed investigation of the relations between this and other thermometers.

The spacing difference between the lines $1\bar{3}1$ and 131 may serve as a measure of the thermal state. Objections to the use of these lines within certain compositional ranges have been raised (e.g. Smith and Gay (1958)) mainly because the line $\bar{2}22$ may disturbe the measurement of the line $1\bar{3}1$. It is possible that the lines $\bar{2}41$ and $24\bar{1}$ will be used in the future for the plagioclase thermometer.

The variation of the $1\bar{3}1/131$ spacing difference versus thermal state and An content is shown in Figure 2, and some selected data are presented in Table 1. It appears that the difference between the temperature recorded by the two-feldspar thermometer and that of

Table 1. Apparent temperatures according to the two-feldspar thermometer and the plagioclase thermometer recorded from coexisting feldspars.

No.	Alkali feldspar		Plagioclase		Geothermal degrees		Remarks
	Δ	%Ab	$\Delta d_{1\bar{3}1/131}$	%Ab	Two-fsp	plag	
1	0.0	9	.1594	75	400	440	All feldspars non-RD
2	0.95	16	.1563	88	475	525	
3	0.98	18	.1540	85	500	510	
4	0 – 0.9	19	.1374	88	500	430	Alkalifsp. RD Plag. non-RD
5	0.8 – 1	24	.1430	85	550	440	
6	0 – 1	21	.1354 – .1207	86	520	350/300	All feldspars RD
7	0.8 – 1	28	.1372 – .1350	89	605	450/430	

1. Granite gneiss, Aukland.

2. — 7. Samples from the Herefos Granite, South Norway, generously placed at the writer's disposal by cand. real. Borghild Nilssen.

Δ, delta value derived from the spacings of the 131 and $1\bar{3}1$ reflections.

$\Delta d_{1\bar{3}1/131}$ derived from the spacings of the $1\bar{3}1$ and 131 reflections.

the plagioclase thermometer is related to the mode of occurrence of Randomly Disordered structures in the co-existing feldspars. If both feldspars are non-Randomly Disordered, approximately equal temperatures are obtained from both thermometers. If the K-feldspar is Randomly Disordered, the plagioclase thermometer temperature is lower than that of the two-feldspar thermometer; and if both feldspars are Randomly Disordered, the plagioclase thermometer indicates a still lower mean temperature.

The results of the feldspar thermometers should be used with care. The plagioclase thermometer is based upon the structural state whereas the two-feldspar thermometer is based upon the partition of Na between plagioclase and K-feldspar. The two phenomena are interdependent in a profound way which we do not fully conceive to-day. It seems reasonable that the two thermometers yield information about slightly different things, and that a specific change in the physico-chemical conditions may induce changes of opposite directions of the two recorded temperatures. The fact that different temperatures are obtained from the two-feldspar thermometer and the plagioclase thermometer is no indication of lack of reliability of either of them.

Both results may be equally reliable and combined they may give information which is more valuable than each of them separately.

I am aware that the influence of numerous factors, like chemical activities and pressure, are not known. These influences may modify the recorded temperatures, but do not detract from the general validity of the plagioclase thermometer.

Discussion

Schuiling (Utrecht)

You assume that between "low" and "high" plagioclases, there is a series of intermediate stages, indicative either of an intermediate temperature or of an incomplete inversion into a stable thermal state. I think this a most interesting idea; when we did experimental hydrothermal work on gneisses, we found that on heating them for several weeks, the plagioclases were in some intermediate stage, which we considered as a failure to achieve high-temperature structure; now in the light of your proposal, it might actually be one of these intermediate-temperature equilibria.

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